3D Maps – Scale, Accuracy, Level of Detail

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Abstract. Nowadays the three-dimensional (3D) maps are very popular and they are an essential part of the cartography. Day after day the cyber 3D worlds become more realistic, more detailed, more accessible to people, who use them for lots of purposes. 3D maps undoubtedly offer very good way for perfect visualization of geographical data but we should know, if this data is correct enough. In the traditional 2D mapping the elements such as scale and accuracy are clearer than in 3D mapping. There is a certain definition about the scale of 2D map and people can calculate the accuracy of the map on this base. The cartographical theory still does not clearly define the same topics about 3D maps. What does large-scale 3D map mean and what does small-scale 3D map mean? The purpose of this paper is to describe and analyze the terms scale, accuracy and level of detail (LoD) in 3D mapping and to provoke a discussion about the topic.

A Questionnaire has been made about the discussed three topics above: scale, accuracy and LoD. The participants in the questionnaire are professionals (cartographers, geodesists, geographers, computer graphics scientists) and also students who are not familiar with 3D modelling. The results helped us to make analyses and to discuss the problems in every one of the pointed topics.

Keywords: 3D map, Scale, Accuracy, Level of Detail

1. Introduction

The modern cartography can be considered as a communication of geo-space information in virtual environment (Rystedt B, 2000) and the map as representation of geographic reality or a tool for delivering of geo-information by visual, digital or tactile way. The development of the modern cartography is instigated by modern technologies and the latest achievements of the spatial geo-software.

The creation of 3D, 4D or multi-D representation is already possible with the help of computer graphics. In this integration, every user will have very easy tool to understand, read and analyze geographic reality. The practical development of geography is going a step before theoretical identification of cartography in this new scientific direction. Many authors speak about 3D maps and give different definitions: Jenny H. M. speaks about 3D maps as "commonly known as landscape panoramas or bird's-eye views" (Jenny H. M, 2011). Artimo K. defines 3D map as combination of digital cartographic data and methods for representation (Artimo K, 1994).

Another definition says that 3D map is a computer, mathematically defined, three-dimensional virtual representation of the Earth surface or another celestial body, objects and phenomena in nature and society. Represented objects and phenomena are classified, designed and visualized under particular purpose (Bandrova T 2001).

On the same way we can find some description of generalization, accuracy, symbol system, level of detail, virtual camera – all of them should be considered as new terms in 3D cartography. Many questionnaires are made mainly in the topics of user's requirements (Zlatanova S & Bandrova T 1998, Zlatanova S et al, 2008). Our aim is to find different opinion about main cartographic terms in 3D mapping given by people worked in the field of geo-science and 3D modelling of the real environment.

The questionnaire contains nine questions about 3D maps. They are divided into three groups: four questions about scale, two questions about accuracy and three ones about Level of Detail. Most of the questions contain multiple choices of answers. The answers were collected online. In this survey people who work, study, or have some interest in 3D cartography participated. There are professionals and students among them. The analyses of the results are made on the base of 15 participants – people who started the survey are 15, and those who finished it are 13. The questionnaire is still open for answering.

2. Scale

The term “Scale” in 3D maps has more complicated understanding than in 2D maps. Participants in the survey show their understanding about the scale of 3D map. **The first question is** “2D maps could be large-, medium- or small-scale ones. In your opinion, could we have the same typology (i.e. large, medium and small-scale) in the case of 3D maps?” There are five possibilities for answering and also a text area where participants are allowed to share their comments. The answers and the results can be seen on *Table 1* and *Figure 1*.

The percent of all participants who gave a relevant answer can be seen in the “Response Percent” column. The number of people given answers can be seen in the “Response Count” column. Some of the respondents gave more than one answer. They think that the scale depends on more than one criterion. Some of them combine the answers: “Yes, Depending on zooming” and “Yes, Depending on LoD”. Others have marked: “Yes, Depending on zooming” and “Yes, Depending on area of visualized territory”. Some of them have found connection between data source and LoD with answers: “Yes, Depending on data source” and “Yes, Depending on LoD”. There is also one participant who combines all possible answers except the answer “No”.

1. 2D maps could be large-, medium- or small-scale ones. In your opinion, could we have the same typology (i.e. large, medium and small-scale) in case of 3D maps?		
	Responses	
	%	Count
Yes, Depending on area of visualized territory	46.7	7
Yes, Depending on zooming	40.0	6
Yes, Depending on LoD	40.0	6
Yes, Depending on data source	13.3	2
No	0.0	0

Table 1. The answers about different kind of scales in 3D maps.

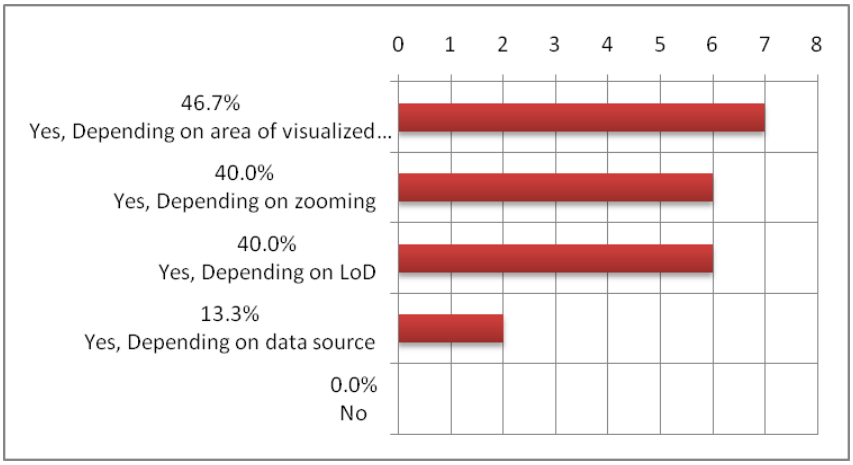

Figure 1. The distribution of answers about different kind of scales in 3D maps.

Most of the respondents (46.7%) answered that 3D maps can be divided into three categories: large, medium and small-scale, depending on the area of visualized territory; 40% of respondents marked "Yes, Depending on zooming" and also 40% marked "Yes, Depending on LoD". Only two people (13.3%) have answered "Yes, Depending on data source".

Some of the respondents added a comment to their answer: "Yes, Depending on zooming, because there are a horizontal scale and a vertical scale. Likewise objects are usually modelled in real size using relevant software." – T.T. "Yes, Depending on LoD - The usage of maps is mostly based on density of content." – D.P.

As a result, there are very different opinions about the scale of 3D maps. But that is not so unexpected. All four positive answers of the first question are interconnected. The scale of the 3D map depends on the area of visualized territory. This also affects the zooming, if we talk about how far or how close we "watch" some part of the Earth. But if we have an interactive 3D map of some territory, we can zoom in and zoom out this model and every time this is the same 3D model but in different viewpoints – closer or not. One of the most important things is the purpose of the 3D map. This fact will influence and define which territory will be visualized, how far will be the viewpoint from the object, and then the LoDs in map content and what will be visualized to the user. Good example is the developed theory by Sun M et al. They declare that some strategies, that they developed, made large-scale 2D and 3D vector data displaying easy in 3D landscape map (Sun et al 2008). The scale is connected again to the sources and not to the final product 0f 3D map.

The second question is directed to the scales of data sources (*Table 2*).

2. In your opinion, which scales of data source are most appropriate for creation of 3D map?				
	for large-scale 3D map	for medium-scale 3D map	for small-scale 3D	Rating Count
1:1	87.5% (7)	37.5% (3)	50.0% (4)	8
1: 500 / 1: 1000	85.7% (12)	35.7% (5)	28.6% (4)	14
1: 10 000	18.2% (2)	90.9% (10)	9.1% (1)	11
1: 25 000	8.3% (1)	83.3% (10)	25.0% (3)	12
1: 50 000	11.1% (1)	33.3% (3)	66.7% (6)	9
1: 100 000 and larger	10.0% (1)	0.0% (0)	90.0% (9)	10

Table 2. The distribution of answers about data source scales used in 3D maps.

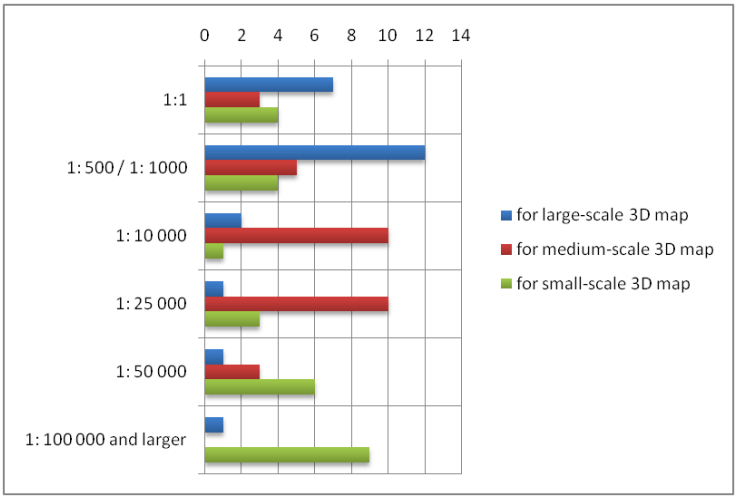

Figure 2. A diagram shows the answers distribution about data source scales used in 3D maps

According to the respondents there is dependence between the scale of 3D map and the scale of data source (see *Figure 2*). Although at the first question only two people answered “Yes, Depending on data source”. At the second question they marked mostly the answers “data sources at 1:500/1:1000 scale” (12 people) and “data sources at 1:1 scale” (7 people) for large-scale 3D map. For medium-scale 3D map there are 10 votes for data source at 1:10 000 and 1: 25 000 scale, and for small-scale 3D map 6 people voted for 1: 50 000 and 1:100 000 scale and larger.

Some of the respondents made comments to their answers. One of them marked "1:1" as an answer for large, medium and small-scale 3D map and explained: "Because objects are modelled in real size and then users can use their desired scale." – T.T. Other has added a comment: "Depends on purpose and area presented in 3D map (city, skiing resort, mountain range, province...)" – D.P.

The third question directs the attention to the represented elements on the 3D map (*Table 3*).

3. According to its scale, what kind of elements should be visualized in a 3D map?				
	for large-scale 3D	for medium-scale 3D map	for small-scale 3D	Rating Count
Terrain; Surface	86.7% (13)	93.3% (14)	80.0% (12)	15
Rivers, hydrographic objects (lakes, dams, etc.)	80.0% (12)	100.0% (15)	86.7% (13)	15
Buildings	86.7% (13)	60.0% (9)	40.0% (6)	15
Roads and railways	80.0% (12)	93.3% (14)	80.0% (12)	15
Textured facades	92.3% (12)	23.1% (3)	15.4% (2)	13
Symbol system for small objects	60.0% (9)	53.3% (8)	46.7% (7)	15
Plants	86.7% (13)	26.7% (4)	13.3% (2)	15

Table 3. The distribution of answers about the elements that should be included on the 3D map.

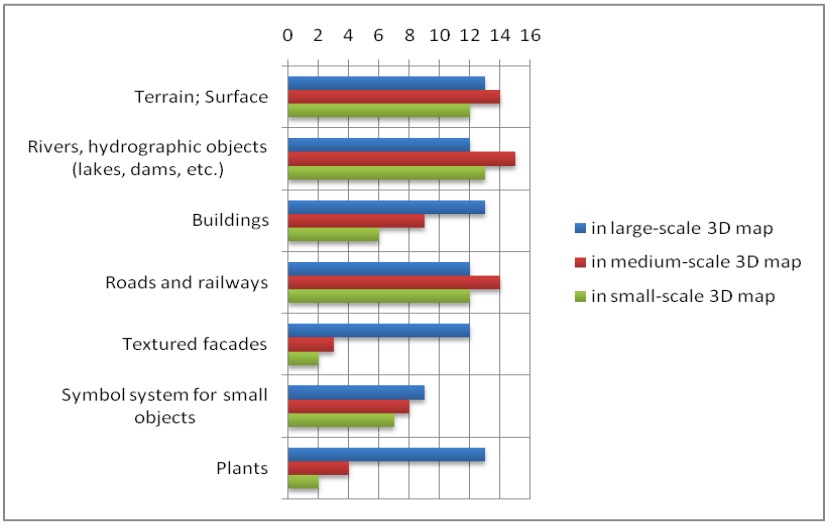

Figure 3. The votes for the elements that should be included on the different types of 3D maps.

The results on *Figure 3* are explanatory enough. Most of the respondents think that a large-scale 3D map should contain all of the listed elements. Elements such as terrain, rivers (hydrographic objects), roads, and railways should be included in all kinds of 3D maps, especially in the medium-scale 3D maps. Elements such as textured facades and plants are considered by most of the respondents as minor details, which are not necessary to be included on the medium and small-scale 3D maps. According to 13 participants "Buildings" should be included on the large-scale 3D maps, 9 of them consider that they should be a part of the medium-scale maps too and 6 of them think that "buildings" should have their place in the small-scale 3D maps also. There is also an added comment: "Built-up areas in small-scale 3D map" – D.P.

The fourth question in our questionnaire and the last one of the section about scale tries to clarify the meaning of the scale 1:1.

4. Do you agree with the term "3D map at a scale of 1:1"?		
	Responses	
	%	Count
No, because it is not possible	60.0	9
Yes	40.0	6

Table 4. Collecting opinions about the term "a 3D map at a scale of 1:1"

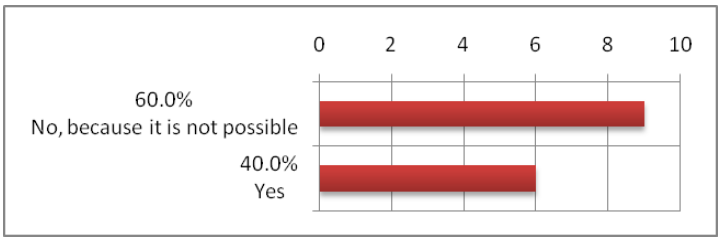

Figure 4. Agreement with the term "3D map at a scale of 1:1"

This term „A scale of 1:1" is used recently and we want to know how people understand it. We have 60% for the answer "No, because it is not possible" and 40% - for "Yes". There is an additional question: "If yes, what is the expected smallest lowest level of detail on the map?" We received three answers of this sub-question: "Buildings and plants" – M.C.; "LoD3" – K.B. Maybe the respondent meant LoD3 which is defined by CityGML (Architectural models /outside/); other one explained: "Yes, only in model space in relevant software".

But what actually does map at 1:1 scale mean? Map which includes everything from the real world in real dimension? Some examples show that this is possible (Kemen et al 2013).

Theoretically every real object can be modelled in 3D cyber world. It could be seen in every little detail. Generalization always exists in cartography and also it depends on the purpose. Practically that is a little bit complicated. On the one hand, it is a lot of work every object and every detail to be modelled. On the other hand, the hardware is still not so advanced to combine so much information. But if the object is not so big, it is completely possible. For example, the data which we obtain by laser scanning and visualise it without generalization, we can treat as a map at 1:1 scale.

3. Accuracy

It is very difficult to define the accuracy of 3D Maps on clear way like mathematical definitions of accuracy of 2D topographic maps. The accuracy of 3D maps can be divided also on two types: horizontal and vertical. Very often they are different and it is not clear which accuracy is higher. Everything depends on data sources accuracy. Usually a cadastral, topographical or other 2D map is used as a base for 3D map creation. As a source, the 2D map has already its own accuracy. If this map is not in digital form the accuracy could go down after data processing.

There are two questions concerning accuracy (*Table 5 and Table 6*).

5. In 2D maps it is possible to calculate the accuracy of the map if its scale is known. In your opinion, is it possible to calculate the accuracy of a 3D map if we know the scale and the accuracy of data sources?		
	Responses	
	%	Count
The accuracy could be different on XY and Z (H) coordinates values	53.3	8
Yes	40.0	6
No	6.7	1

Table 5. Opinions about calculating the accuracy if the 3D map.

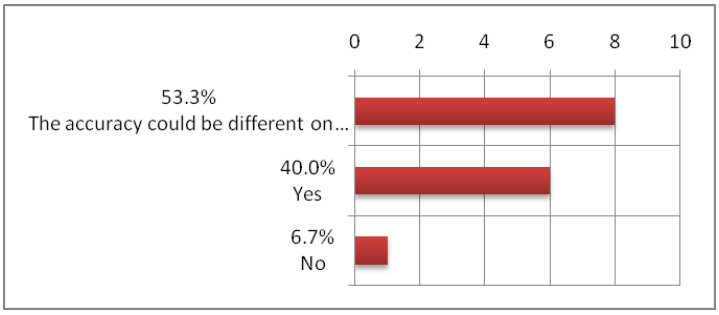

Figure 5. A diagram shows the answers distribution about calculating the scale of the 3D map.

On *Figure 5*, there are 53.3% answers for "The accuracy could be different on XY and Z (H) coordinates values", 40% have answered "Yes" and there is also one answer "No".

By the second question about factors that impact accuracy, we gave five possibilities for answering (*Table 6*).

6. In your opinion, which factors impact the accuracy of 3D maps?		
	Responses	
	%	Count
Data sources	86.7	13
Data processing	60.0	9
Technology of 3D map creation	53.3	8
LoD	53.3	8
Software	33.3	5

Table 6. Distribution of votes for the factors which impact accuracy.

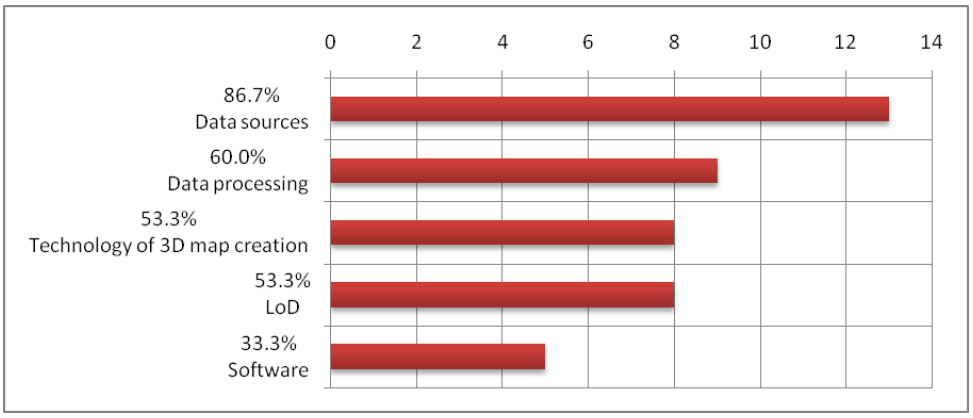

Figure 6. Distribution of votes for the factors which impact accuracy.

The most answers are (86.7%) for “Data sources” You can see all results on *Figure 6.*

Undoubtedly, data sources affect the accuracy of a 3D map. Initial accuracy of 3D models always starts with the accuracy of the source. It is very important this accuracy to be enough for the purpose of the 3D map. If we need this 3D model for some kind of simulation, the accuracy must be higher. If we make a map of mountain range, then we will use a medium-scale map and the accuracy of this map is lower than a map at a scale of 1:000.

Data processing also affects the accuracy. If we use a paper map as a data source, first we have to scan this map. If we use a large format scanner, then we have some stretching of the image by one axis. Then we have to georeference and digitize the image which also makes the accuracy down. If we use geodetic measurements or photogrammetry, then we have more correct data. The third factor which influences the accuracy is the technology of creation and data collecting.

Five people voted for “Software”. The software has some influence of the accuracy but it is very small and we will ignore it.

Two of the respondents have added comments: “Generalizaiton always plays a crucial role in map accuracy” – D.P.; “Different LoDs have different accuracy (e.g. LoD 1,2 and 3 accuracy is defined by totally different parameters than LoD 5 and 6 and should be defined separately)” – K.B.

4. Level of Detail

Six levels of detail are proposed. Almost all objects which should exist on a 3D map are included and distributed into different themes. (See the list with LoDs *on Table 7)*.

7. We propose 6 levels of detail to be included in a 3D map. Please, select the LoDs that should be included on a 3D medium-scale map? You are invited to share your comments in the textbox below the question.		
	Responses	
	%	Count
LoD1 (terrain and terrain objects, hydrograph)	84.6	11
LoD2 (infrastructure)	76.9	10
LoD3 (extruded buildings)	76.9	10
LoD4 (building's roofs)	30.8	4
LoD5 (3D architectural elements and/or photorealistic textures)	15.4	2
LoD6 (3D symbol system)	46.2	6

Table 7. The proposed Levels of Detail.

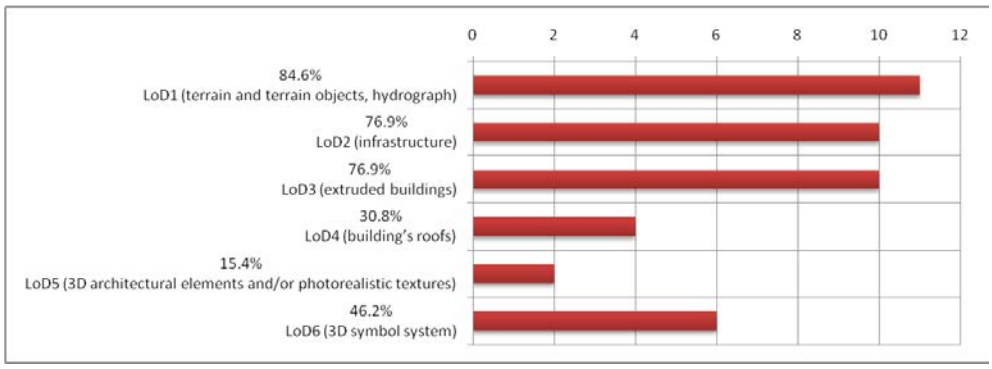

Figure 7. Opinions about which LoDs should be included on a 3D medium-scale map.

Participants in the questionnaire were asked which LoDs should be included on a 3D medium-scale map. We received very different combinations of this LoDs. *Figure 7* shows the results. More than 75% of respondents marked LoD1, 2, 3. LoD1 leads convincingly by 84.6%. LoD4 and 5 are con-

sidered by most of respondents as unnecessary detail for 3D medium-scale map. It is a little bit different by LoD6 – 46.2% respondents. There is also very appropriate comment: "It also depends on the zoom factor and the purpose of the map. 3D medium-scale map in some cases should contain architectural elements; in some cases – not, even extruded buildings." – M.D.

The second question is directed to LoD1 (terrain, terrain objects, hydrology). Should be LoD1 divide into more LoDs?" The responses are 54% "Yes" and 46% "No" (*Table 8, Figure 8*).

8. Do you think that LoD1 (terrain, terrain objects, hydrology) should be divided into more LoDs?		
	Responses	
	%	Count
Yes	53.85	7
No	46.15	6

Table 8. Opinions about dividing LoD1 into more LoDs.

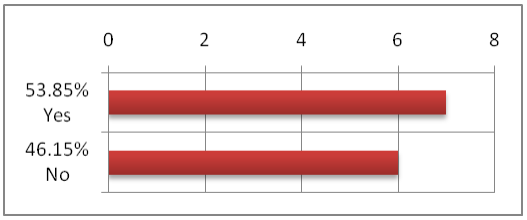

Figure 8. . Opinions about dividing LoD1 into more LoDs.

The comments about this question are the following:

- "Yes, either predefined or computer on the fly. Look at Google Earth: zooming in and out changes the LOD of the terrain.";
- "Yes, according to distance from view point." – D.P.;
- "Yes, Especially for 3D large-scale maps." – M.D.;
- "Yes, depending on the scale which is used." – T.T.;
- "Yes, in two maybe." – S.M.

The last question in this survey is: "In CityGML LoD cannot exist without previous one (You cannot create LoD4 if you didn't complete LoD3). Do you think that in 3D map LoDs can exist independently one from another (for

example LoD1, LoD3, LoD6)?" There are 13 positive answers and only two are negative ones. The comments are:

- "Yes, sure. If the objects can be created independently at different scales." –M. C.
- "Yes. Your LODs span different themes whereas CityGML LODs span different representations of the same object. Note that you run into the same problem with your LOD 3 and 4; you cannot have LOD4 without LOD3 (or you'll have floating roofs)."
- "Yes, but limited: LoD1 is always crucial; especially LoD6 is quite independent from the others." – D.P.
- "Yes. Too many LoDs can harm the readability of a 3D map."
- "Yes. They should be able to exist independently, so depending on the application of the map some can be excluded. For example LoD1 for large scale maps. Or in some maps LoD6 might be significant while LoD5 is not needed and can be replaced by photo-texturing (e.g. touristic maps)." – K.B.
- "If we use a single constant LoD as basis for all exports it could be possible."
- "Yes, but then this is a hybrid 3D map." – T.T.
- "No. There is need from hierarchy." – S.M.

The idea to separate the different LoDs was to make them independently one from another or they could exist separately unlike the LoDs defined by CityGML. They represent different LoD of city models (building) and there are also some problems with separating them (Stoter J at al 2012).

LoD1 should be divided into different LoDs, because a 3D map can represent only a terrain without hydrographic objects. The terrain surface also can be divided into different LoDs but they can be named Sub-LoDs.

There is a little misunderstanding in the definition of LoD4. As all others LoDs, LoD4 also should exist separately. The specification "building's roofs" involves the roof as a next level of detail on the extruded building including the building. LoD5 also upgrades LoD3 and 4 - 3D architectural elements and/or photorealistic textures as parts of a whole building and its roof. In future it should be included in the specification of LoD4 (extruded buildings with roofs).

These LoDs have been defined as a description of objects which have to exist on a 3D map, together or not, depending on the scale of the map or its purpose. It is possible Sub-LoDs to exist where different objects can be modelled with different details. For example, the terrain could be modelled as more complicated TIN included more polygons or not so complicated

(simplified) TIN. The representation of the terrain is considered as a special part of LoD for 3D graphics. There are a lot of algorithms described by authors – specialists in computer graphic (Luebke D at al 2003). In this case the term LoD has two aspects: cartographical and computer graphics one. Computer graphics LoD means different levels of reduction of geometry and texture, according to the distance from the camera (Mach & Petschek 2007). In this way the simplification of the object can be automatic. Some authors offer a level of detail algorithm which helps the successful representation of multiple data layers in multiscale visualisation (Engin B at al 2009). This is very useful for creating interactive 3D maps and animations.

5. Conclusion and directions for future works

The questionnaire survey should continue in 2 directions: more participants should be included and another way of survey: practical achievements, users' requirements, technology developments.

Some definitions of the considered topics should be proposed and other ones, like definition of 3D map, could be examined by professionals and users. The based definition on which some researches could be start is given in Introduction.

Other topic is the scale. It depends on the area of visualization, zooming and LoDs. More investigations will show if it is possible to divide 3D maps on large, medium and small scale ones. The results in Table 2 and Figure 2 clearly show that large-scale 3D maps need sources at scale 1:1000 and larger, middle-scale 3D maps need sources at scale 1:10 000 to 1:25 000 and small-scale 3D maps – 1:50 000 and smaller scale sources.

According to the scale different kinds of elements could be included in a 3D map (*see Table 9*).

Elements, contain in 3D map	Large-scale 3D map	Medium-scale 3D map	Small-scale 3D map
Terrain; Surface	++	++	++
Rivers, hydrographic objects (lakes,	++	++	++
Buildings	++	+	?
Roads and railways	++	++	++
Textured facades	++	-	-
Symbol system for small objects	+	+	+
Plants	++	-	-

Table 9. Elements, visualized in different kinds of 3D map according to scale: ++ very much needed; + needed; - not needed; ? – need more survey.

The accuracy is different on XY and Z/H coordinates and it depends mostly on data sources and data processing, partly on technology for 3D map creation and less on software. We need to do more investigations to clarify which objects will be included in LoDs.

Acknowledgements:

The authors would like to thank all colleagues who participated in the questionnaire and would like to invite them to discuss and find the best solutions for describing theoretical aspects and terminology of 3D mapping.

If you like to participate in this survey, please go in:
http://www.surveymonkey.com/s/H3R77GP

References

Artimo K (1994) The Bridge between Cartographic and Geographic Information Sysytems. Helsinki University of Technology. Visualization in Modern Cartography. Ed. By Alan M, Maceachren. Vol 2, USA.

Bandrova T (2001) Symbol System for 3D City Maps. PhD Theses, University of Architecture, Civil Engineering and Geodesy, Sofia.

Engin B, Bozkaya B, Balcisoy S (2009) Introducing Level of Detail to 3D Thematic Maps, GeoViz 2009, March 3-5, 2009, Hamburg

Jenny H M (2011) Geometric Design Alternatives for Computer-generated 3D Maps Inspired by Hand-painted Panoramas. PhD Theses, Diss ETH No 19790.

Kemen B, Hrabcak L, Mihalovic T (2013) Outerra www.outerra.com. Accessed 24 March 2013

Luebke D, Reddy M, Cohen JD, Varshney A, Watson B, Huebner R (2003) Level of Detail for 3D Graphics, Elsevier Science (USA), ISBN: 1-55860-838-9, pp. 390

Mach R & Petschek P (2007) Visualization of Digital Terrain and Landscape Data, A manual, Springer, ISBN 978-3-540-30490-6, pp. 365

Rystedt B (2000) Meeting the ICA's Top Executives, ICA News, No 34, pp. 2-3, June.

Sun M, Lv G. L, Lei C (2008) Large-Scale Vector Data Displaying For Interactive Manipulation in 3D Landscape Map. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B4. Beijing pp. 507-511.

Stoter J, Ledoux H, Meijers M, Ohori KA (2012) 7th International Conference on 3D Geoinformation, May 16-17, 2012, Québec, Canada

Zlatanova S, Itard L, van Dorst M (2008) User Requirements for Virtual Environments Used to Model Buildings at the Urban Scale. IBPSA-NVL 2008 Event, Eindhoven, Nederland – Paper ID:19.

Zlatanova S & Bandorva T (1998). User Requirements for the Third Dimensionality. E-mail Seminar of Cartography “Maps of the Future”, pp. 61-72, Sofia.